Impacts of an assembly kit logistic solution in renovation projects: a multiple case study with camera-based measurement

Müge Tetik (muge.tetik@aalto.fi)
School of Engineering, Civil Engineering,
Aalto University, Espoo, Finland

Antti Peltokorpi
School of Engineering, Civil Engineering,
Aalto University, Espoo, Finland

Jan Holmström
School of Science, Industrial Engineering and Management,
Aalto University, Espoo, Finland

Olli Seppänen
School of Engineering, Civil Engineering,
Aalto University, Espoo, Finland

Abstract

Logistics solutions are crucial for efficiency, especially in renovation projects with tight schedule. Manufacturing industries use kitting of assembly parts to improve time efficiency in assembly. Even if it is a promising solution in renovation projects, there is no empirical research on its impacts in renovation. We examine whether apartment-based assembly kits improve renovation projects' workflow. A multiple case-study design compares two projects: with and without the solution. Two cameras collected data for performance measurement in the selected apartments. The study generates insights on how kits prepared by a logistic provider in consolidation center can improve on-site performance.

Keywords: Construction logistics, Kitting, Camera-based measurement.

Introduction

Construction projects are one-time manufacturing processes where the resources are temporarily brought together to deliver a unique construction product. Due to this project-based and fragmented nature of the construction industry, management activities are required in order to ensure the delivery of the product in a timely manner without sacrificing the quality requirements. Logistics solutions are an important element for successful completion of the projects (Sobotka et al., 2005). Any action for improving the

cost and schedule of the activities such as planning, production and delivery affect the project performance positively. Logistics solutions are mechanisms that are used to control the material and information flow in each stage of operations, however, their benefits are neglected in the construction industry unlike the manufacturing industries (Vidalakis et. al, 2011). Although logistics solutions contribute to productivity, they are not perceived as substantial activity in construction industry since they are prone to budget cuts (Sullivan et al., 2011; Sundquist et al., 2018).

Renovation projects in apartment buildings operate under high pressure in order to shorten the period during which inhabitants cannot use their flats (Alhava et al., 2015). Reliably shortening the project time is a challenge because surprises in demolition work and apartment-specific customized material requirements make the planning and control of work and material flows a difficult task. Utilizing logistics solutions in renovation projects assists overcoming these difficulties. However, the adoption of logistics solutions is slow in traditional construction industry (Sullivan et al., 2011) and the benefits of logistics solutions have not been realized in the construction industry (Sundquist et al., 2018).

According to Seppänen and Peltokorpi (2016), the relationship between the storage location and labor productivity gained less attention in the construction logistics literature. One practice related to storage location and assembly operations is kitting. Kitting is a logistics solution where the parts are supplied to the assembly operations by previously sorted kits (Hanson and Medbo, 2012). The types of kitting can be used for productivity increase by efficient usage of material locations. For instance, kitting decreases the time that is spent to search for the parts to be used in assembly operations (Hua and Johnson, 2010). There is a need for generating practical information regarding the effectiveness of this solution in construction context.

We conduct a research regarding the effects of apartment-based kitting in pipe renovation projects. We investigated two projects of a case company in which the company adopted an agile approach and prepared the detailed plan of the work schedule and the materials to be used in the apartments prior to the start of the project. The required materials are supplied by the apartment-based kits prepared by their consolidation center. The purpose of this research is to investigate whether apartment-based assembly kits improve the workflow of building renovation projects. The contribution of this paper is on the combination of logistics solution and assembly work productivity.

In the following sections, we first review the literature related to the logistics solutions. Then, we describe our methodology and state our findings based on our analysis. Lastly, we provide discussion and conclusion sections.

Theoretical background

Theoretically, this research combines two research streams: (1) logistics solutions used in construction field and (2) kitting in manufacturing industries.

Logistics solutions in construction

There are several logistics solutions utilized in construction operations in order to improve the management of resources such as materials and time. According to Knaack et al. (2012), logistics is a tool to save time and cost on-site as shorter construction time and decreased need for storage increases cost savings. Including a logistics specialist advances performance on-site by improving efficiency in the site activities, increases the use of site resources and decreases the interference between building activities and materials handling (Sundquist et al., 2018).

Consolidation centres are one of the logistics solutions where the consolidation facilities keep the materials for a period of time till their delivery to the shops or sites on a just-in-time (JIT) basis by the logistics workers (Sullivan et al., 2011). Sundquist et al., (2018) suggest that logistics resources such as logistics hubs can be utilized in an efficient manner through expanding of the scale of the operations. Hamzeh et al. (2007) state that logistics centers can be configured to be used for the purposes such as assembly and kitting as well as consolidation, sorting and breaking the bulks.

Just-in-time delivery is the delivery of materials to construction sites to be installed immediately without being stored (Tommelein and Li, 1999). This type of delivery can partially decrease the need for an on-site storage area (Jaillon and Poon, 2014) and increase the quality and efficiency (Pheng and Hui, 1999). Make-to-stock as well as engineer-to-order materials can be procured and delivered on a JIT basis. JIT delivery can be combined with the assembly kits.

Vendor managed inventories (VMI) is a solution where vendors monitor the inventory levels of the buyer which decreases the costs and improves material availability and resource utilization (Waller et al., 1999). According to Tserng et al. (2006), site materials managed by the vendor could reduce the construction site inventory and congestion. This solution can be used for materials purchased in bulk. VMI is utilized as a logistics solution in construction industry where it improved the small item logistics (Tanskanen et al., 2008).

Off-site manufacturing technique involves prefabricated and standard components to be produced in controlled environments and carried to the site to be assembled (Khalfan and Maqsood, 2014). It is a widely used technique for decades which moves the operations from on-site to off-site. According to Ballard and Arbulu (2004), it is the manufacturing of parts of an object in a different place than its final installation place. Thus, from the logistics perspective, it decreases the need for a site storage when it is combined with JIT delivery. Prefabricated components have also higher added value than bulk materials delivery considering the transportation operations (Safa et al., 2014). Prefabrication manufacturers can make use of bulk purchases while prefabricated components are usually engineer-to-order parts.

On-site market places are the site warehouses for collecting materials and small tools and equipment. Workers are given the materials and equipment on the service counters. The market places contain myriads of materials from a complex supplier network (Arbulu et al., 2003).

On-site material tracking activities are developing to improve transparency and control of material deliveries. GPS, RFID and Bluetooth technologies are enabling these activities and utilized for resource positioning in construction (Lu et al., 2007). The construction industry efficiency and logistics could be improved via enabling tracking of the assets and by so managing the operations accordingly. Many different kind of materials can be tracked via the above mentioned technologies.

Kitting as a logistic solution to improve assembly work

In manufacturing industries, kitting of assembly parts has been proposed as a logistic solution to improve time efficiency in manual assembly (Hanson and Medbo, 2012). Kitting is a material supply system that is employed in order to group different components into a package according to the assembly schedule (Limère et al., 2012). The components in the kits are manufactured or purchased from the suppliers and retrieved, prepared, and placed in kits (Hua and Johnson, 2010). Ding and Puvitharan (1990) mention that kitting reduces the searching time of a part and material handling as well as increases the control over the work in progress. According to Jiao et al. (2000), kitting

practice reduces the setup costs by converting internal setup into external setup that constitutes a large share in assembly operations' costs. Most relevant to this paper is the type of kitting described by Tanskanen et al. (2008), where the materials are delivered in the right amount and right time when there is no inventory space used on site. Since one of the motives for employing the kitting practice is to have the necessary parts and instructions ready before the start of the assembly operation (Choobineh and Mohebbi, 2004), utilizing kitting possibly improves workflow in renovation projects, which often consist of multiple consecutive tasks performed by different specialized workers. Since the effects of apartment-based kitting practice in construction industry has not yet been covered by the literature, we choose to investigate potential improvements through this logistic solution in this study.

Method

A multiple case-study design (Yin, 2013) was adopted for theory testing (Ketokivi and Choi, 2014). We selected two projects of a Finnish contractor using theoretical sampling: one project with and one without the assembly-kit logistics solution. With the new solution, the contractor first prepares a detailed plan of the on-site material usage schedule and uses a consolidation center managed by a logistics provider who prepares and delivers the assembly kits to the apartments with the required materials. The logistics provider delivers the kits to the apartments every day after the completion of the previous task. Therefore, the practice attempts to produce a smooth flow in the delivery and assembly of apartment-based materials. In the project without the logistics solution, the materials are delivered to site storage without apartment-based kitting.

We collected both qualitative and quantitative data for data triangulation. There are several data sources. First, we observed the work site of the project with the logistics solution and the consolidation center. Second, we interviewed the project manager, site supervisor, and the operations manager of the logistics provider about the design of the new practice and their experiences related to production planning, material kit preparation, delivery, and on-site installations. Third, bill of materials were used to compare the work schedule with the delivery dates in order to obtain the actual work schedule. Lastly, we analyzed video footage of both projects over two weeks using a camera that takes photographs when movement was detected in the apartments. Trucco and Kaka (2004) mention a framework that uses a camera and tracks the progress on site. Gong and Caldas (2009) state a computer vision based model to interpret the videos from construction operations into productivity data. The contractor company placed cameras to the selected apartments during the projects in order to obtain information for performance measurement. This novel data-collection method allowed us to calculate the workplace utilization rate, which is based on the share of time when a worker is working on the apartment. A high utilization rate indicates better workflow of a single apartment, namely the product flow. Thus, to have a high utilization rate, the time when no value is being added to the apartment should be minimized. It requires less of the worker's time is spent seeking, collecting, and transferring materials outside of the apartment. Daily utilization rates were calculated by dividing the total working time in the apartment with the time difference between the first and last value-adding task of the day.

Findings

Based on the interviews, the actors' experiences with the solution were positive in terms of work time and cost compared to the project using conventional logistics solution. The contractor company thinks that there is potential in investing on this practice in their future projects.

According to the interviews, the new solution saved the workers time because they could do what they were actually hired for rather than walking around collecting and transferring materials. Increased productivity decreases the duration of the project and, ultimately, the cost. However, delivery of the heating, ventilation, and air conditioning (HVAC) materials in the new solution caused problems. There were a lot of parts that were not delivered because those materials were not included in the material use plan in the beginning. As a result, there were delays associated with delivering and installing these materials. Since a manager, rather than a site worker, did the planning of HVAC materials, some of the parts were missing and some excess parts were ordered. After the problem has been recognized, required updates were made in the bill of materials.

Our analysis also revealed that there are many opportunities for improving the developed practice for future renovation projects. The drawings of the building were not accurate and that is why there were design issues and the constructability of the models were weak. Moreover, there were instances where the required materials were not known until it was too late. Logistics operations can only work if required materials and delivery times are known. The operations manager of the consolidation center stated that "*Company and people are not the problem. Problem is leadership and planning.*"

Figure 1 shows the workflow of activities in the logistic solution. The consolidation center received materials from the material providers and then prepared the apartment-based kits and delivered them to the site every day. In the ideal situation, the plans were ready and the materials were in the consolidation center two weeks before the start of the tasks. On the site, the three box system for materials was used in each apartment; the first box held the new material coming from the consolidation center. Unused materials were put to the second box by the workers and the third box held the garbage. The kits were carried to the apartments while the excess materials from previous day's kits were removed from the second box. Damaged materials were sent back to the consolidation center. The kits were also task-based so one worker used one kit. Tasks moved from one apartment to another consecutively so the extra or unused materials from the kits were carried to the site storage or another apartment which has the same operation scheduled or sent back to the consolidation center.

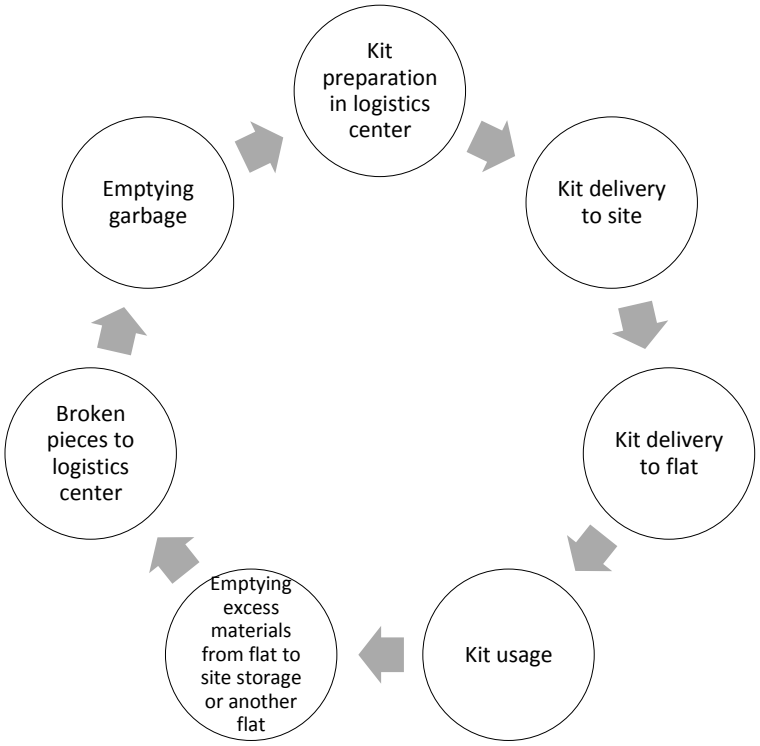

Figure 1 – Material process of the assembly kit logistic solution.

Each apartment went through the renovation operation for the planned two weeks' time and the overall project duration was one month. There were in total seven deliveries made for each apartment. The contractor company used several suppliers for different materials that were put into kits in the consolidation center. Consolidation center prepared the next two days' kits and could send them early or late depending on the on-site schedule changes. Thus, in this practice, single-piece-flow suggested by Arbulu and Ballard (2004) was applied where two days was the single piece.

The building has three floors and six vertical plumbing lines which contain three different types of apartments, so the planning of the materials and delivery were done considering the similarities and differences among the apartments. Kits were grouped together and delivered to the apartments which are on the same line unless there were customer specific requirements. In this case, these custom kits were delivered individually.

Figure 2 presents the workplace utilization rates of the two projects; one with and another without the logistics solution. The average workplace utilization with the logistics solution is 38.5% while it is 31.5% without the logistics solution which can be due to random variation. The first 14 days with the logistics solution has the workplace utilization rate of 37.7 %. The standard deviation of the workplace utilization rates with the logistics solution in the first 14 days is 14.3 while it is 15.5 without the logistics solution. This suggests that the utilization rate is smoother in the case with the logistics solution.

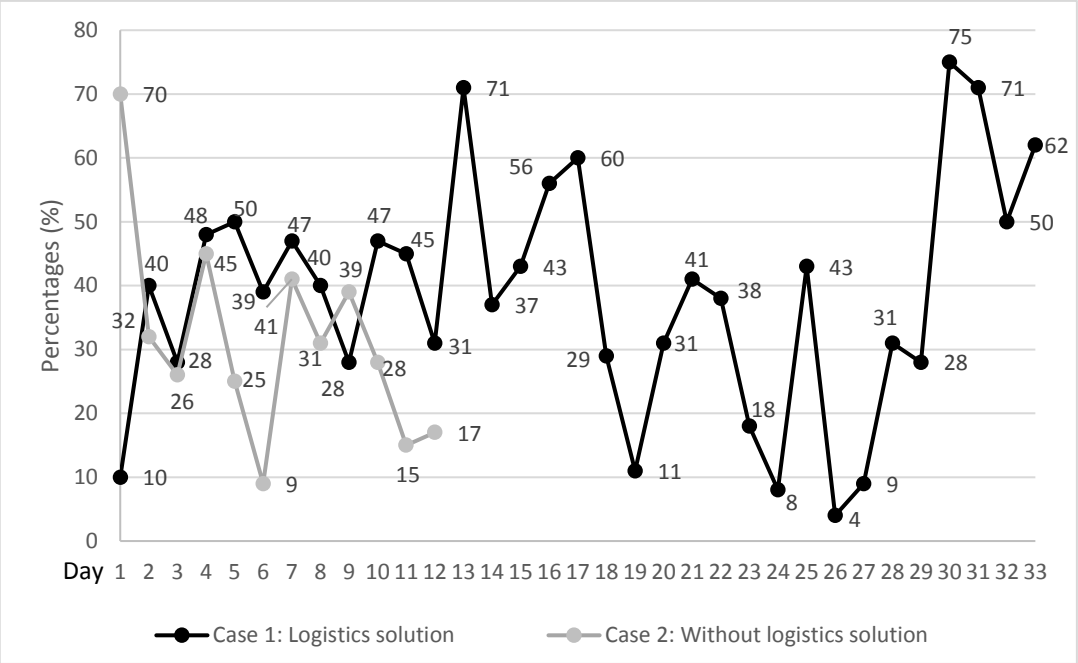

Figure 2 – Daily workplace utilization rates in selected apartments.

According to the interviews with the project manager, the forecasting during the project was a difficult task and there were problems with the delivery of the plumbing materials. They reacted late to these problems.

> *"I don't know, more visible schedule where it would have been easier to see that where the work is going now and when the materials should have been delivered, if the work continues at the same pace."* (Interview, project manager).

Moreover, the three box system was not properly followed by the workers and the apartments became clustered by the unused materials which were left in the first box through the time. The project manager explained that the reason for the delay was in shifting focus from flow efficiency toward resource efficiency on-site:

> *"We focused too much on the resource efficiency, and not enough on the flow efficiency, and what I mean by that is that when you have this kind of material delivery plan, just the sequence of apartments, in which order they are done, should be impossible to change …[]… but at some point it was a mess, so people went from this apartment there and back here and so there was no order at some point, anymore, so that's why the schedule performance was a bit poor."*

We can conclude from the workers' experiences that having the materials closer to the work place enabled them to focus on the actual task itself and the work on site progressed well. Namely, the logical placement of the kits to the actual work place generated positive feedback from the workers. The project was a learning project for the contractor company and they achieved their cost target. There was not a significant difference between the costs of the selected renovation projects.

The materials listed in the bill of materials were identified and classified in terms of their area of usage. The actual schedule of the work was derived from analysing the videos as well as the bill of materials and the actual material delivery dates. The actual schedule matches well with the planned schedule except for the delay caused by the customer specific requirements in the selected apartment with the camera, which moved electricity work towards the end of the project (see Figure 2). There were initially no planned activities after day 14. When we compare the actual delivery dates of the task specific material kits with the project schedule, there is no big gap between the material deliveries

and its usage. For instance, after the plumbing materials arrive, the plumber does the tasks according to the planned schedule. Overall, the material kit delivery dates resemble the work schedule in terms of materials of a task and the planned tasks.

Discussion

The workplace utilization rates obtained from the video footage analysis of the case with the logistics solution were better than the case without the logistics solution. However, this might be due to random variation. However, task and apartment based kits enabled workers not to search for the required parts elsewhere than their actual work place.

The match between actual schedule and the planned schedule shows the opportunities associated with having detailed planning for efficient operations. Integrating the complete and detailed information early in the design phase enabled the case company to monitor the work flow and materials and increased the control over them. The project using the assembly-kit logistics solution generated positive feedback and results for the case company. According to Brynzér and Johansson (1995), kitting improves the logical placement of the parts that decrease the travelling time of the workers to the picking point. Based on the video footage analysis and interviews with the case company, the apartment-based kitting provides room for performance improvement in terms of work place utilization which would affect the performance of the project.

Managerial issues caused the most of the problems encountered during the project. According to Opfer (1997), many systems interacting each other forms the buildings and the design and construction processes requires a significant control by the contractor and construction manager. Even though the information regarding the materials, locations and schedule were integrated into the steps of the operations, the planning of the required materials and forecasting became problematic and the case company made the corresponding new information updates late. This implies that the management should put more effort into planning and control and be more agile so that there are not deviations from the plan and updates of the plan of the operations based on the new information were done properly.

As stated earlier, there were problems regarding using the box system by the workers. The unused pieces were either left in the apartment or in the first box, causing the apartment to be clustered with the leftover materials. Not sending the excess materials to the other apartments on the same line may have caused waste. In order to avoid such problems, consolidation centre started to provide more personnel on-site to increase their control over the materials. They also started to do sub-assemblies in the consolidation centre in order not to use specialized workers' time for small assembly operations which could be done beforehand. For further improvements in future projects, Takt time planning (Frandson et al., 2014) can be used in renovation projects as it is practiced in marine industry (Heinonen and Seppänen, 2016).

Limitation and further research

The research is limited to comparing only two projects; therefore, the findings are context-specific and may include random variation. Future research should compare different assembly kit strategies in several projects and utilize video footage to analyse the delivery of materials, such as dwell times and completeness in the use of kits. Using more than one video camera in an apartment can enable obtaining footage from more angles and a complete picture which would allow the visibility of the kits and enable to calculate the consumption rate of the kits. Other possible solution to track materials is to use other technologies, such as Bluetooth Low Energy technology. Moreover, image

processing techniques can be utilized to analyse the videos to speed up the performance analysis process.

Conclusion

The study provides preliminary findings from apartment-based assembly kits, which are prepared and delivered by the logistics service provider and may improve on-site workflow. The research makes three contributions: (1) it contributes to research on logistics solutions in construction by suggesting that assembly kits could be an appropriate solution to improve performance of renovation projects. (2) The research contributes to measurement methods in construction by applying a novel camera-based status evaluation as a new data-collection method. Finally, (3) the study demonstrates how integrating task schedule, bill of materials, and location information enables smooth material delivery and assembly which can be later integrated into the building model. Planning the work schedule and materials in detail and preparing apartment- and task-based kits can be an appropriate solution for improving performance in renovation operations. The approach of the management plays a significant role in terms of adaptation towards such practices. The constructability of design models is another aspect for the planning activities and logistics solutions be more effective. A more successful application of the practice can be done after realizing the shortcomings in the learning project and using the lessons learnt by both logistics and the case company and developing improvement ideas in the future projects.

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